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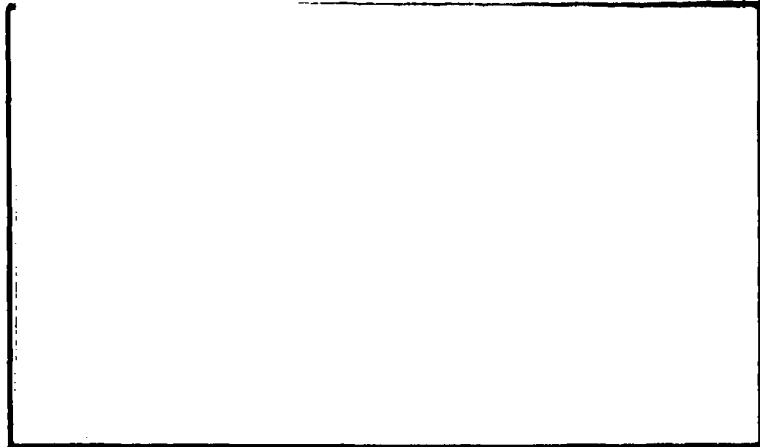
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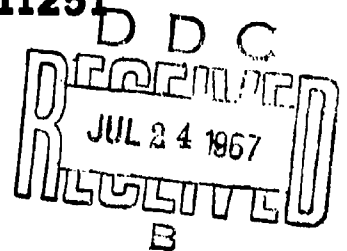


AD817193



TECHNICAL MEMORANDUM

U.S. NAVAL APPLIED SCIENCE LABORATORY
FLUSHING & WASHINGTON AVES.
BROOKLYN, NEW YORK 11251



CRACK GROWTH PROPERTIES OF WELDS

IN HY-80, HY-100 AND HY-130/150

HIGH STRENGTH STEELS

IN A SEA WATER ENVIRONMENT

Lab. Project 9300-1
SF 020-01-01

Technical Memorandum #39
Task 0722

16 September 1965

MATERIAL SCIENCES DIVISION

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SUMMARY

Initial experiments have been conducted on welded high strength steel plate type specimens subjected to the corrosive effects of sea water under cyclical and static loading. Butt welds in 1 inch thick HY-80 and HY-130/150 steel plates and a mechanically peened tee fillet weld in 1-1/2 inch HY-100 steel plate have shown high resistance to crack propagation under stress corrosion conditions.

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- 1 - Stress Corrosion Results on HY-80, HY-100 and HY-130/150 Steel Welded Plates

ADMINISTRATIVE INFORMATION

Ref: (a) NAVAPLSCIENLAB Program Summary of 1 May 1965, SF 020-01-01,
Fabrication of High Strength Steel Alloys
(b) NAVAPLSCIENLAB Project 9300-1, Progress Report 1 of 15 Apr 1964
(c) NAVAPLSCIENLAB Project 9300-1, Technical Memorandum #31 of 14 Jun 1965
(d) NAVSHIPYDNYK Lab Project 6160-2, Progress Report 3 of 17 Jul 1961
(e) NAVAPLSCIENLAB Project 9300-23, Progress Report 1 of 13 Sept. 1965

1. In connection with its high strength steel program, outlined in reference (a), the U. S. Naval Applied Science Laboratory is investigating the crack growth properties of high strength steels in a sea water environment. This memorandum covers the results of initial studies on welded high strength steel plate type specimens subjected to the corrosive effects of sea water under cyclical and static loads. Although the data obtained are of a preliminary nature, they are being reported at this time because of the important significance of the results obtained on wide plate type specimens which have otherwise been shown to give dramatic results on metals susceptible to stress corrosion.

OBJECTIVE

2. The object of this work was to determine the effect of sea water environment on the crack growth properties of welded high strength steels under cyclic and static loads.

DESCRIPTION

3. Three specimens were used in this phase of the investigation:

a. One 32x28x1-1/2 inch plate type specimen of HY-100 steel with a central longitudinal tee-fillet weld that had been mechanically peened. The assembly was fabricated with MIL-110-18 type electrodes in accordance with prevailing Bureau instructions. Details of the joint design and welding and mechanical peening procedures are similar to those used for HY-80 plates reported in reference (b). The mechanical properties and the chemical analysis of the HY-100 tee-fillet plate identified as 59AP26 are given in Table 1 of reference (c). The plate had been subjected to fatigue in an air environment in the Plate Fatigue Machine, described in reference (d), at a nominal stress of 80,000 psi until the formation of fatigue cracks caused a 10 percent increase in deflection to a total of 0.301 inch. The plate had surface cracks on both sides of the stiffener.

b. One 22x20x1 inch HY-80 plate type specimen with a central longitudinal butt weld. Details of the joint design and welding procedure are shown on Figure 1.

c. One 22x20x1 inch 5 percent Ni HY-130/150 plate type specimen with a central longitudinal butt weld. Details of the joint design and welding procedure are shown on Figure 2. Visual examination of the 2 butt welded plates prior to testing revealed no surface cracks at the toe of the weld.

METHOD

4. The plates were subjected to cyclic or static loading in sea water environment as follows:

a. The cracked mechanically peened HY-100 tee-fillet specimen was subjected to static loading at a nominal stress of 80,000 psi at the toe of the weld in the Plate Fatigue Machine for 1,000 consecutive hours. The plate was simply supported along the 32-inch edges at a span of 28 inches, free along the two short edges and uniformly loaded over the entire surface.

b. The HY-80 butt welded specimen was subjected to cyclical and static loadings in a smaller Plate Fatigue Machine. The plate was simply supported along the 22-inch edges at a span of 20 inches, free along the two short edges and uniformly loaded over the entire surface. The number of cycles, the number of hours under static load, and the stress levels that the plate was subjected to are indicated graphically on Figure 3.

c. The HY-130/150 butt welded specimen was subjected to a similar procedure as the HY-80 butt welded specimen. The number of cycles, the number of hours under static load, and the stress levels that the plate was subjected to are indicated graphically on Figure 4.

5. The method of retaining the sea water around the critical section of the butt welded specimens while under cyclical or static loading is illustrated in Figure 5. A similar arrangement was used for the tee-fillet welded specimen. The dam was formed from a sealing compound and the sea water was changed daily in order to maintain the salt concentration as constant as practicable.

6. During the course of the test a chart record of deflection at the center of the plate was obtained for cyclical and sustained loading. Corresponding deflection data were also obtained by means of 2 dial indicators. Visual observations were made to determine when cracks first appeared and how they progressed to various lengths along the critical section of the welds.

7. Prior to finish machining the butt welded HY-80 and HY-130/150 plates, measurements were made to determine residual stresses adjacent to the weld using a hole drilling technique. In each case the hole was drilled in the section of the plate which was to be removed. The location of the hole relative to the weld and edge of plate is shown in Figures 6 and 7. Procedures for determining residual stresses were similar to those reported in reference (e). Briefly, a 7/16 inch hole was drilled 7/16 deep at the center of a strain gage rosette consisting of eight equally spaced radial strain gages on a 5/8 inch diameter circle. As shown in Figures 6 and 7, it was necessary to drill the holes near the edges of the original weldments, in material to be subsequently removed, thereby providing suitable undamaged plate type specimens. Run-off tabs were removed from the HY-130/150 plate prior to drilling, but not removed from the HY-80 plate.

RESULTS AND DISCUSSION

8. The mechanically peened HY-100 tee-fillet welded specimen which had been cracked under cyclical loading in air showed no stress corrosion effects when the plate was held for 1,000 hours at a nominal stress of 80,000 psi under a salt water environment. Detailed data are given in Table 1. The indicated crack length represents the average of cracks on both sides of the stiffener.

9. Stress corrosion data obtained on the HY-80 butt welded plate type specimen under a sea water environment are listed in Table 1 and shown graphically on Figure 3. The specimen did not show any marked increase in deflection as a result of cracking until after 15,000 cycles of zero to 80,000 psi stress and 120 hours under a static stress of 80,000 psi. At 19,384 cycles the deflection exceeded a 100 percent increase over the initial deflection and during a continuation of the test under static loading the deflection showed a negligible increase up to 580 hours and no increase from 580 to 788 hours at which time the test was stopped.

10. Stress corrosion data obtained on the HY-130/150 butt-welded plate type specimen in a sea water environment are also listed in Table 1 and shown graphically on Figure 4. Since only one specimen was available the data shown plotted on Figure 4 are the result of a combination of cyclical and static loadings in order to obtain maximum data from the specimen. It will be noted that all cycling was conducted at 100,000 psi and that the static load was increased so as to raise the stress level from 100,000 psi to 130,000 psi and cause more rapid crack propagation. This occurred only after the increase in deflection over the initial deflection was 100 percent which is usually considered ultimate failure in the cyclical test. It will be observed from Figure 4 that

after the surface crack length reached 22 inches (the total length of the weld), the specimen sustained 1420 cycles of stress at 100,000 psi and 127.5 hours under a nominal static stress of 130,000 psi before ultimate failure occurred. Figure 8 is a photo of the cracked plate after the stress corrosion test.

11. Relaxation strains shown on Figure 6 for the HY-80 butt weld indicate compressive residual stresses in the plate away from the butt weld which rise to relatively high tensile stresses at the toe of the weld. Based on a linearly varying residual stress distribution, and following the procedures of reference (e), residual stresses at the toe of the weld were calculated to be 140,000 psi tension parallel to the weld and 47,000 psi tension transverse to the weld. Since the yield strength of the steel is approximately 80,000 psi the high value of 140,000 is not considered truly representative but the indications are that the true residual stress is at least equal to the yield strength. It should also be noted from Figure 6 that the hole was drilled 2-1/2 inches from the edge of the plate to which a run-off tab was attached. Thus, while the residual stresses measured do not represent precise determinations, they do indicate that the butt weld subjected to stress corrosion studies did contain high residual stresses at the weld.

12. Figure 7 shows a fairly irregular pattern of residual strain distribution for the HY-130/150 butt welded plate. Following the procedures of reference (e) the residual stresses at the toe of the weld were calculated to be 24,800 psi compression transverse to the weld and 11,800 psi tension parallel to the weld. These apparent irregular results have been noted in other measurements on butt welds and indicate that further study is required on residual stresses in butt welds and the effect of welding sequence and procedures on the magnitude and distribution of these stresses. The residual stress measurements on the HY-130/150 specimen indicate that the butt weld subjected to stress corrosion tests contained relatively low surface residual stresses.

CONCLUSIONS

13. The results of this work show that the following welded high strength steels which have been pre-cracked in fatigue show high resistance to stress corrosion cracking:

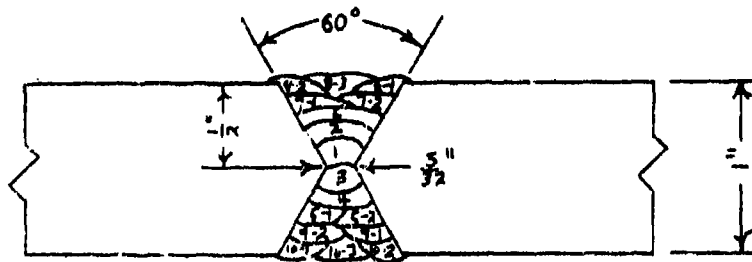
- a. Mechanically peened tee-fillet welds in 1-1/2 inch HY-100 plate
- b. Butt welds in HY-80 1-inch plate
- c. Butt welds in 5 percent Ni HY-130/150 1-inch plate.

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14. On the basis of limited results, initial high residual stresses in HY-80 butt welds do not appear to have any significant effect on the stress corrosion resistance of the weldment. A similar conclusion cannot be drawn for the HY-130/150 butt weld because the measured residual stresses were low.

FUTURE WORK

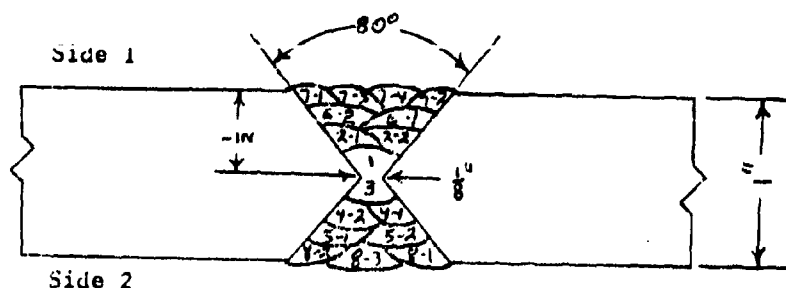
15. Tests similar to those conducted on the 5 percent Ni HY-130/150 alloy, currently being conducted on a 9 percent Ni 4 percent Co (180,000 psi yield strength) alloy, will be reported in approximately 3 months.



Specimen No.: 85B1
Base Metal: HY-80
Electrode: MIL-11018, 5/32" dia.
Preheat: 200°F
Interpass Temperature: 200-300°F
Current & Polarity: Direct current, reversed polarity
Position: Flat
Heat Input: 45,000 joules/inch

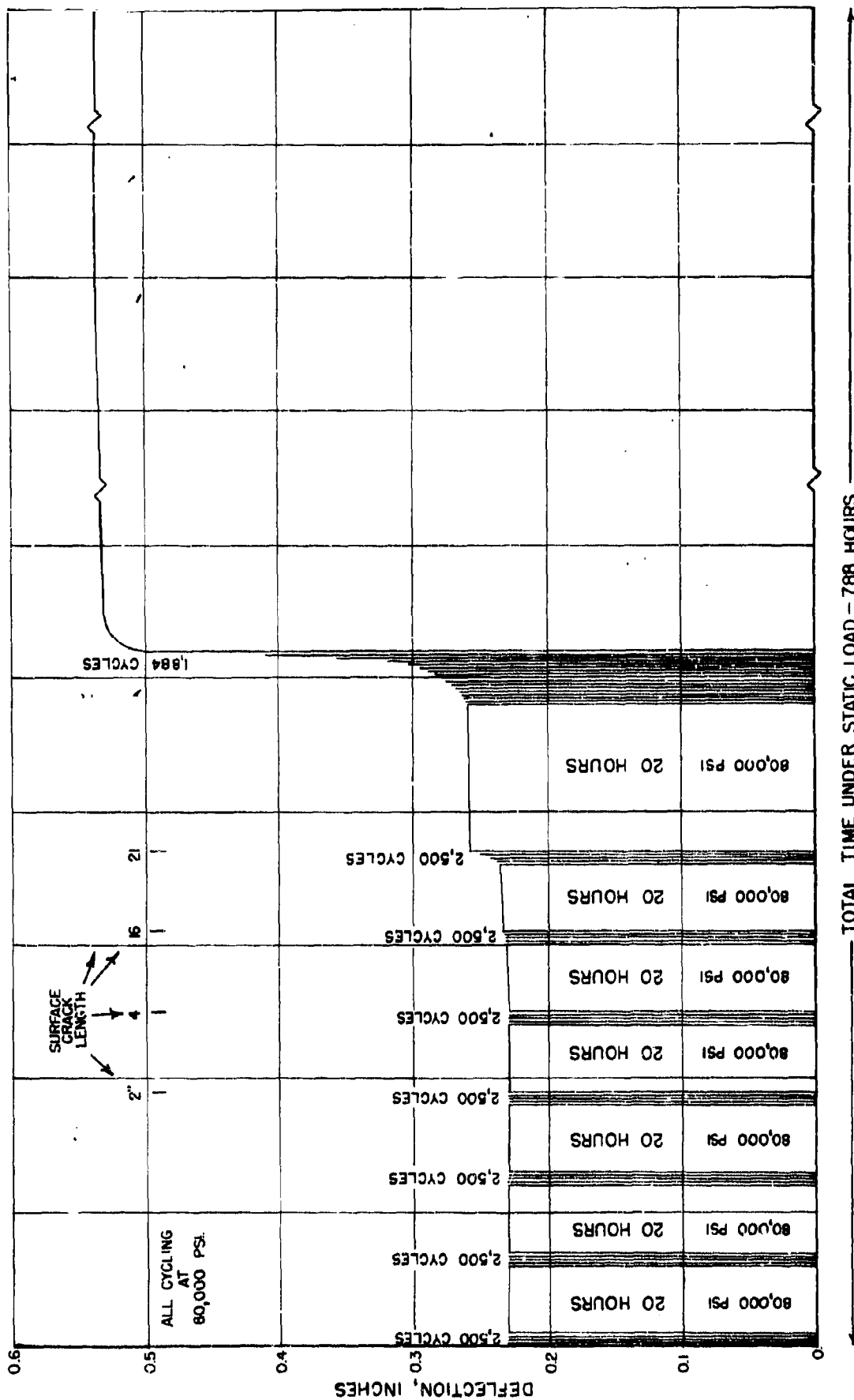
Remarks: Block technique used on first two layers.
Root ground before depositing third layer.

FIGURE 1 - Details of Joint Design and Welding Procedure of 22x20x1 in. HY-80 Butt Welded Plate Type Specimen



Specimen No.:	83B1
Base Metal:	5% Ni HY-130/150, U.S.S. Heat No. XS3588, Plate No. 090339
Weld Metal:	Code A, 1/16" dia.
Process:	Metal Inert Gas - Spray Transfer
Shielding Gas:	99% Argon, 1% Oxygen at 50 CFH
Preheat & Interpass Temp:	250 - 300°F
Current & Polarity:	Direct Current, Reversed Polarity 320 - 350 Amps, 30 Volts
Position:	Flat
Heat Input:	45,000 joules/inch
Remarks:	Grind root before depositing third layer.

FIGURE 2 - Details of Joint Design and Welding Procedure of 22x20x1 in 5 percent Ni HY-130/150 Butt Welded Plate Type Specimen



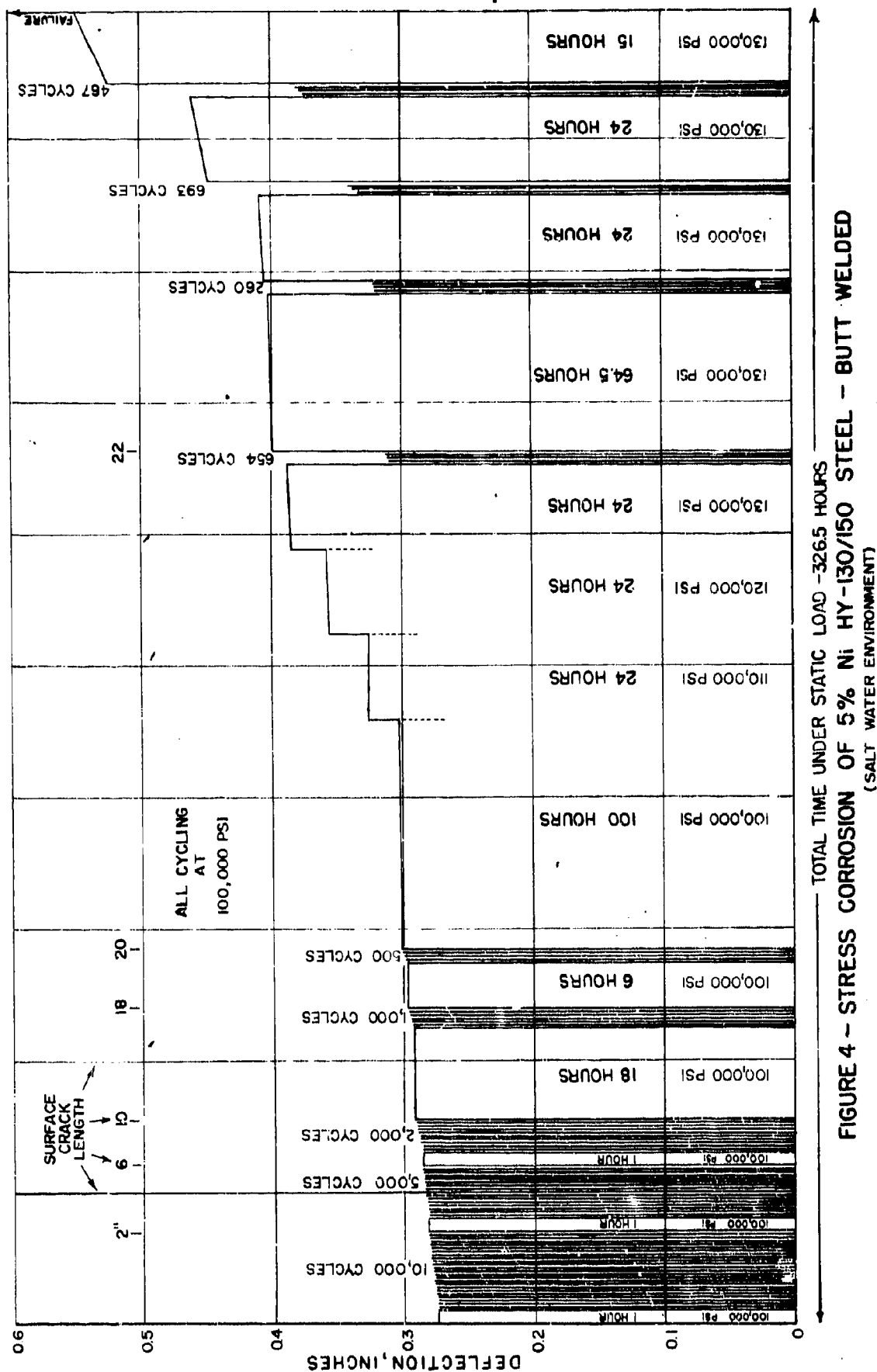


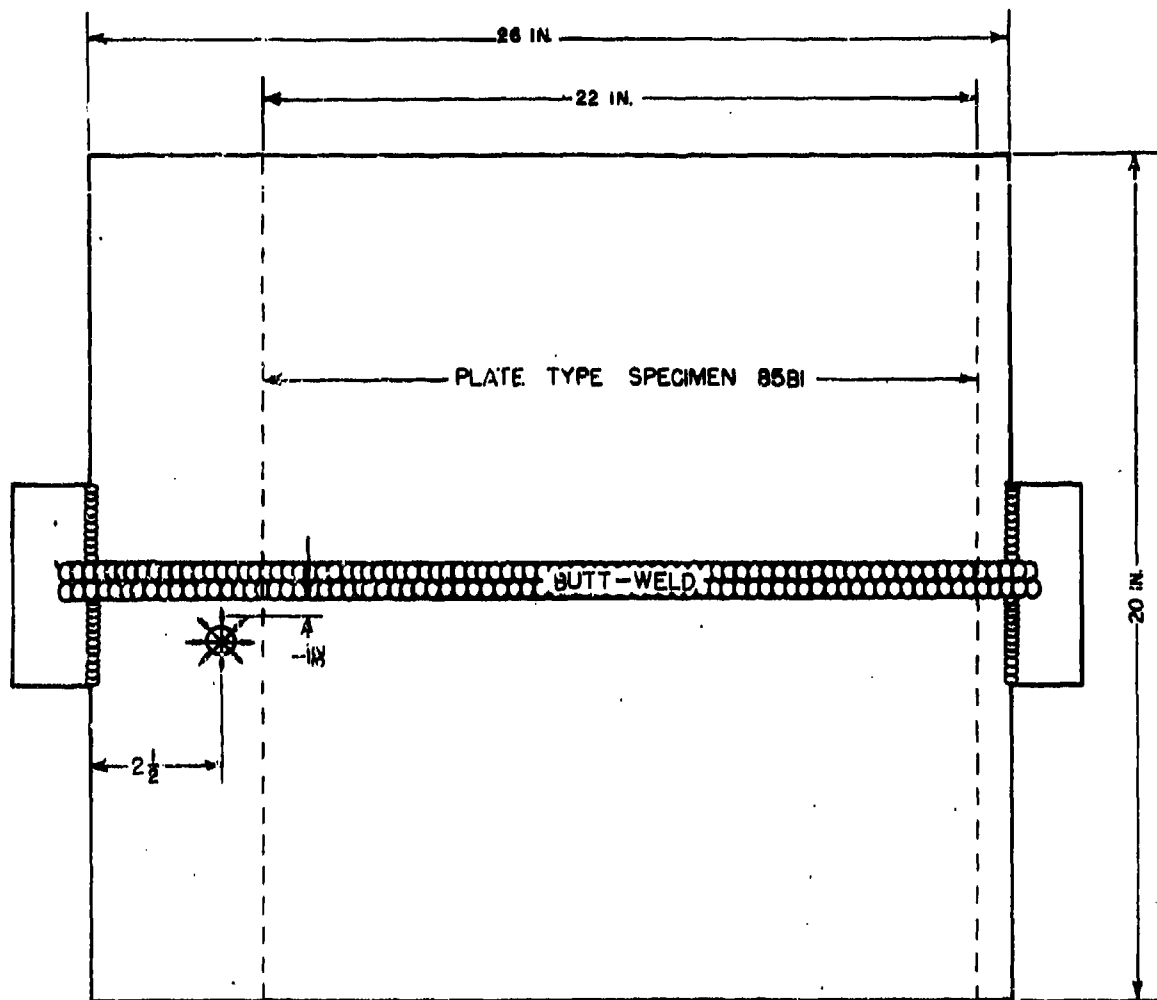


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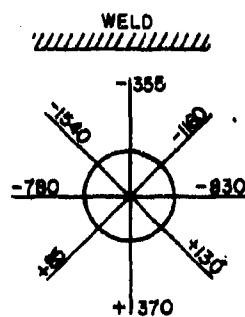
FIGURE 5 - METHOD OF RETAINING SEA WATER ON BUTT WELDED PLATES DURING STRESS CORROSION TEST

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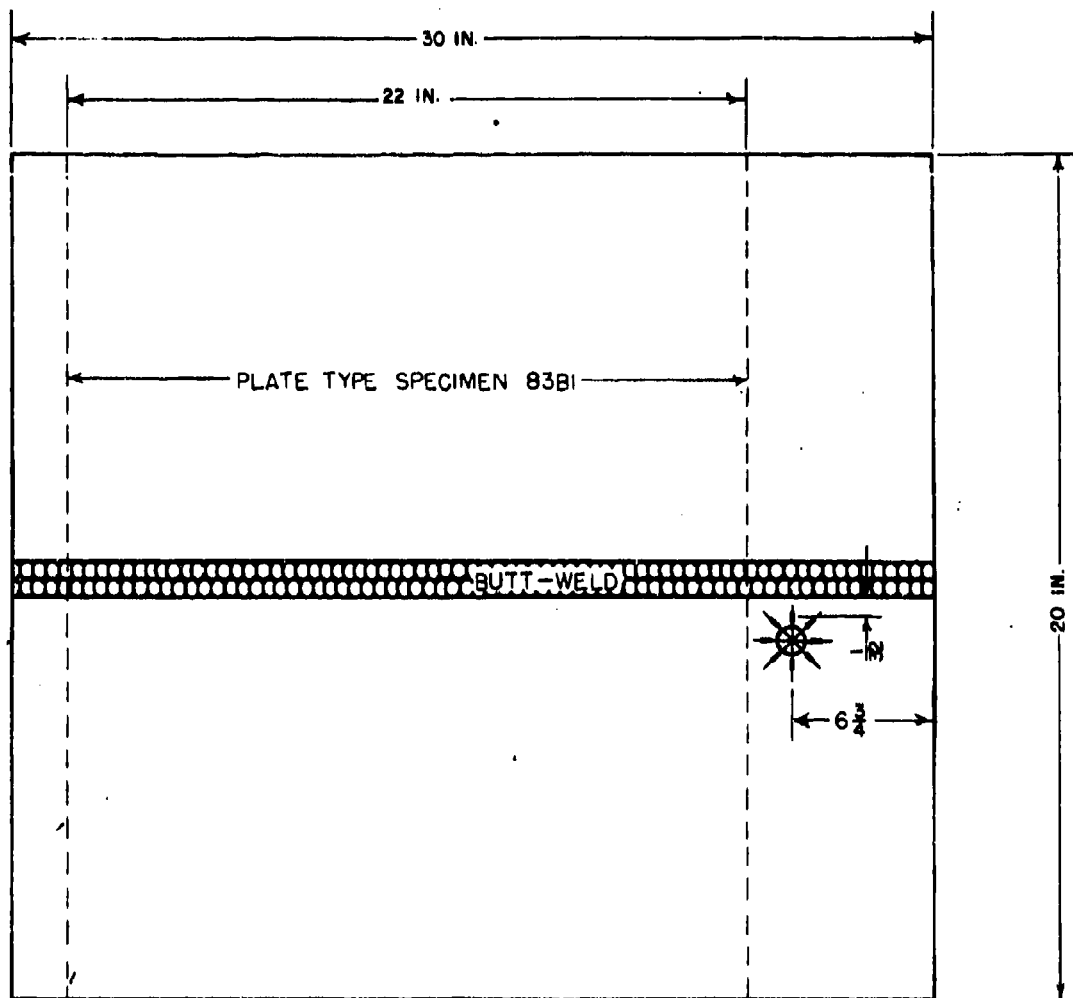


HOLE DIA. 7/16 IN.
HOLE DEPTH 7/16 IN.
GAGE CIRCLE DIA 5/8 IN.
C6-IXIM50A STRAIN GAGES
0.080 GAGE LENGTH

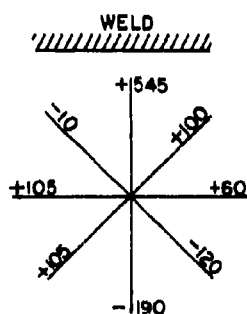


MEASURED RADIAL
RELAXATION STRAINS
IN MICROINCHES

FIGURE 6-HOLE LAYOUT FOR RESIDUAL STRESS MEASUREMENTS IN
BUTT-WELDED 1 IN. HY 80 PLATE



HOLE DIA. 7/16 IN.
HOLE DEPTH 7/16 IN.
GAGE CIRCLE DIA. 5/8 IN.
G6-IXIM50A STRAIN GAGES
0.050 GAGE LENGTH



MEASURED RADIAL
RELAXATION STRAINS
IN MICROINCHES

FIGURE 7 - HOLE LAYOUT FOR RESIDUAL STRESS MEASUREMENTS IN
BUTT-WELDED 1 IN. HY 130/150 PLATE



PHOTO L-19951-2

FIGURE 8 - BUTT WELDED HY-130/150 PLATE TYPE SPECIMEN AFTER
STRESS CORROSION TEST

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TABLE 1

STRESS CORROSION RESULTS

BUTT WELDS

	5% Ni HY-130/150	HY-80
Specimen No.	83B1	85B1
Average Thickness, (in)	1.008	1.000
Nominal Stress, (psi)	100,000	80,000
Initial Deflection, (in)	0.274	0.230
Final Deflection, (in)	0.600	0.554
No. of Cycles to 10% Increase in Deflection	18,500	17,250
No. of Cycles to 100% Increase in Deflection	20,574	19,384
No. of Hours in Sea Water	326	788
Length of Crack	At 10% Increase in Deflection	19-1/2
	At 100% Increase in Deflection	22

FATIGUE CRACKED MECHANICALLY PEENED HY-100 TEE-FILLET WELD

Specimen No.	59AP26
Average Thickness (in)	1.507
Nominal Stress (psi)	80,000
No. of Hours Under Sea Water	1,000
Initial Deflection (in)	0.301
Final Deflection (in)	0.301
Initial Crack Length (in)	26
Final Crack Length (in)	26

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DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U.S. NAVAL APPLIED SCIENCE LABORATORY FULSHING & WASHINGTON AVENUES BROOKLYN, NEW YORK 11251		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	
		2b. GROUP	
3. REPORT TITLE Crack-Growth Properties of Welds in HY-80, HY-100 and HY-130/150 High Strength Steels in a Sea Water Environment			
4. DESCRIPTIVE NOTES (Type of report and, inclusive dates) Technical Memorandum (Apr-Sep 1965)			
5. AUTHOR(S) (First name, middle initial, last name) P. Abramov			
6. REPORT DATE 16 Sep. 1965		7a. TOTAL NO. OF PAGES 17	7b. NO. OF REFS 5
8a. CONTRACT OR GRANT NO. b. PROJECT NO. 9300-1 c. SF 020-01-01 d. Task 0722		9a. ORIGINATOR'S REPORT NUMBER(S) Technical Memorandum 39	
9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)			
10. DISTRIBUTION STATEMENT No. 4: Each transmittal of this document outside the Department of Defense must have prior approval of NAVSEC 6101D.			
11. SUPPLEMENTARY NOTES		12. SPONSORING MILITARY ACTIVITY Naval Ship Systems Command Washington, D. C.	
13. ABSTRACT <p>The objective of this work was to determine the effect of sea water environment on the crack growth properties of welded high strength steels under cyclic and static loads.</p> <p>Initial experiments have been conducted on welded high strength steel plate type specimens subjected to the corrosive effects of sea water under cyclical and static loading.</p> <p>Butt welds in 1 inch thick HY-80 and HY-130 steel plates and a mechanically peened toe fillet weld in 1¹/₂ inch HY-100 steel plate have shown high resistance to crack propagation under stress corrosion conditions.</p>			

DD FORM 1473 (PAGE 1)
1 NOV 65
S/N 0101-807-6811

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A-81400

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
1. Sea water environment						
2. Crack growth properties						
3. High strength steels under cyclic and static loads						
4. HY-80 butt welds						
5. HY-130 butt welds						
6. Crack propagation						
7. Stress corrosion						